Reduction of urban water downflows through micro-basins dispersing in the subsoil

Réduction des rejets urbains par l'utilisation de micro-bassins d'infiltration

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RÉSUMÉ

Nous présentons un dispositif efficace de réduction des pics d'écoulements dans les réseaux d'assainissement urbains, dans des zones analogues à celles de la Plaine du Pô, caractérisées par un climat tempéré avec des intempéries au printemps et à l'automne.

Ce dispositif permet d'atteindre les objectifs suivants :

a) éviter la construction de grands bassins pour écrêter les crues ;

b) minimiser les dimensions des réseaux d'assainissement urbain.

Il offre également l'avantage, par rapport aux solutions analogues disponibles dans la littérature technique, d'éviter les infiltrations dans le sous-sol des premières eaux de pluie notoirement polluées.

Les développements hydrologiques ont été calculés par un système de modélisation par la méthode des éléments finis.

MOTS CLÉS

Systèmes d'assainissement, bassins d'écrêtement, capacité d'inondation

ABSTRACT

We present here an useful device for the flood peaks reduction in urban drainage networks, in territory areas analogous to the Po Plain, characterized by a temperate climate with spring and autumn rains.

The device reaches the following goals:

a) avoids the construction of huge basins for the lamination of the floods;

b) reduces to a minimum the urban drainage network's dimensions.

It also offers the advantage, compared to analogous solutions available in technical literature, of avoiding the subsoil infiltration of first rain, notoriously polluted.

The hydrologic elaborations have been performed with finite elements mathematical modelling.

KEYWORDS

Sewage systems, detention basins, full flood capacity

1. INTRODUCTION

The device consists of a detention basin for the rain water influx coming from a single pluvial (or road drain) with collection and dispersion in the subsoil, hence the name “micro” dispersing basins.

The device tends to satisfy the territory hydraulic invariance principle (changes of land use shall not increase the flow in the drainage network ; the Emilia plain drains were constructed for rural areas with inflows of only 5÷10 l/s x hm2), both in relation with discharges and in relation with volumes, whenever applied in systematic way in new urbanizations:

- the flood capacities are reduced by means of detention of the floods in each micro-basin;

- the volumes are reduced by means of infiltration in the subsoil of the water collected in each micro-basin.

It has not to be confused with the drain well, although similar in functionality, because the micro-basin discussed has an hydraulic link with the public drainage network; it has also a geometrical development mainly in the two surface directions, because the high depth in a plain is not compatible with the presence of the underground water, reason for which the drain wells are scarcely ever used.

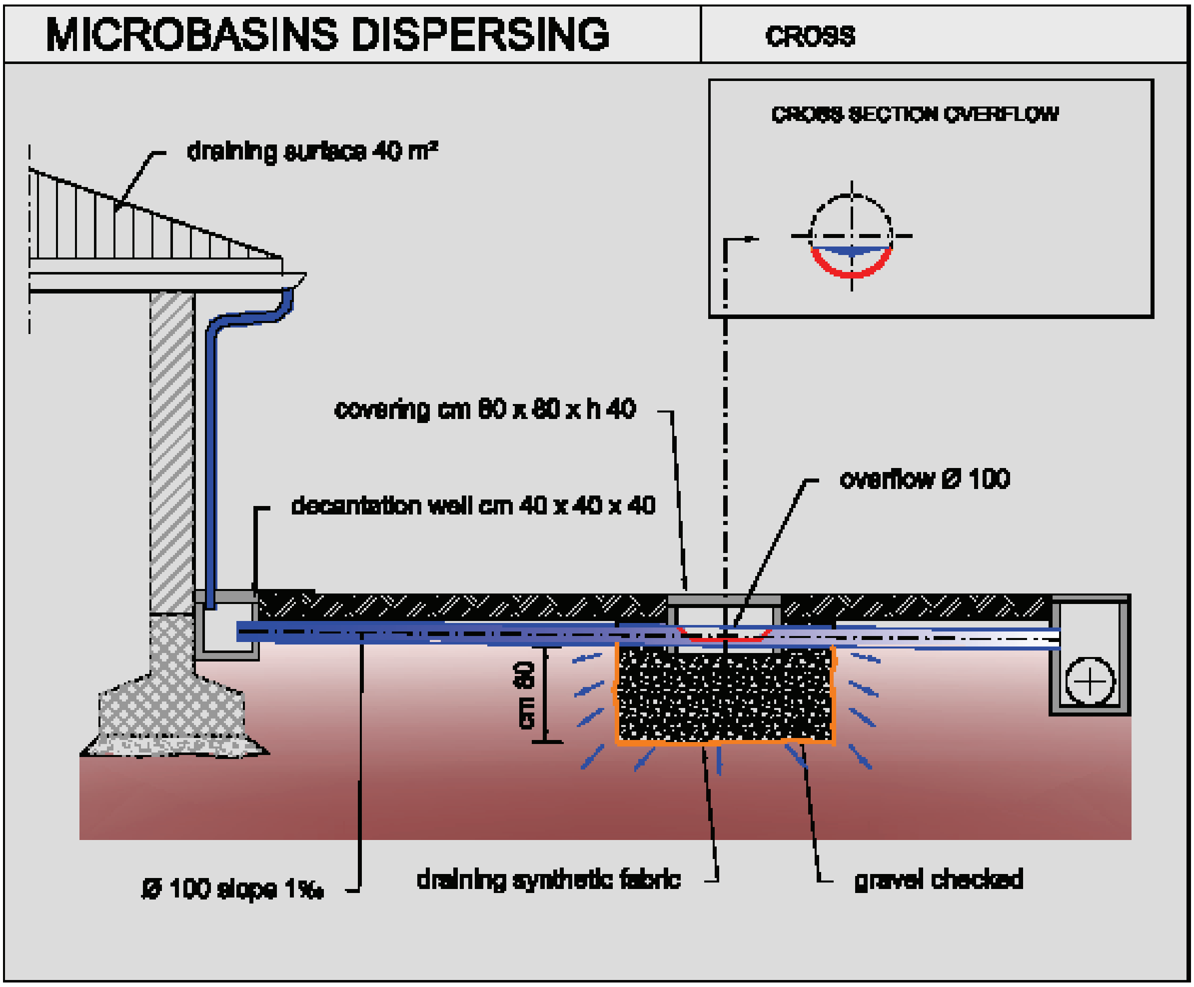
2. DESCRIPTION OF THE DEVICE

The device object of hydrologic evaluation is here below described in its technical and functional aspects; for a deeper understanding, we invite the reader to observe the drawing in *Figure 1*.

The device is based on the interposition between the fallpipe basis and the drainage network of a volume to be used as expansion for the rain water, whose surface in contact with the ground in situ is suitable for the subsoil dispersion; once the basin is filled, even though the dispersion is still active, it is possible to avoid the backing up on the pluvial with a simple overflow towards the drainage network.

An hollow is filled with the required quantity of gravel (the detention volume is the vacuum space among the gravel particles), after covering the hollow’s surface with a draining syinthetic fabric as a border and a separation between gravel and ground.

The drainage pipe of the pluvial, before connection to the drainage network, runs above the gravel block and, by means of the removal of a great deal of its cylindrical cap, is able to determine the downflow in the gravel of the flood capacity exceeding the minimum acceptable levels in the network.



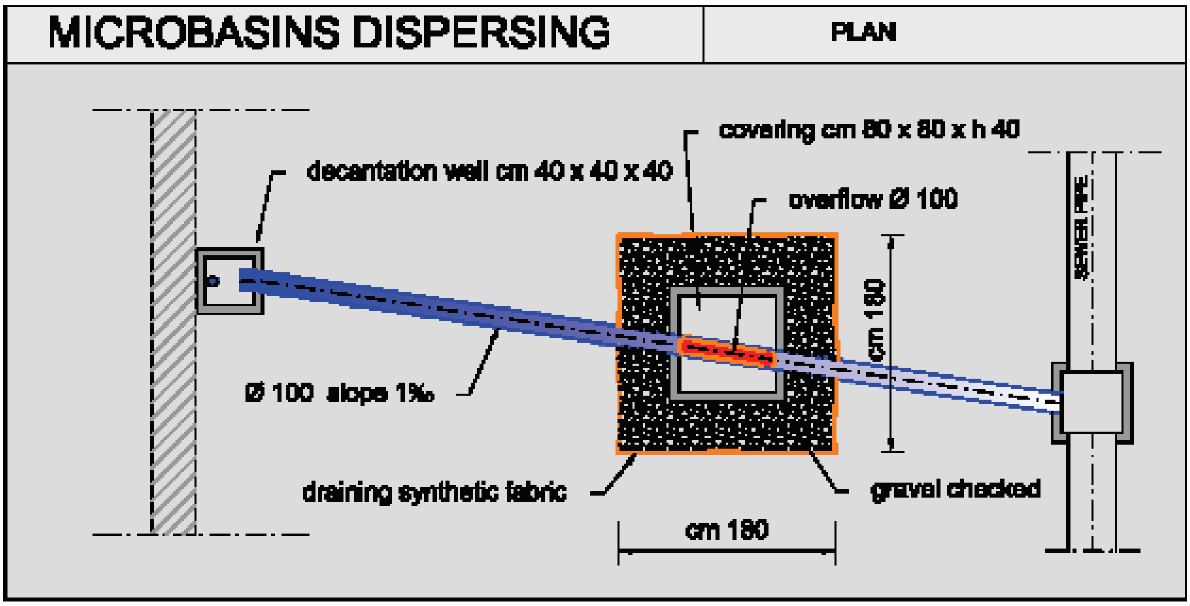


Figure 1: micro-basin cross end plan

This pipe constitutes the overflow of the dispersing micro-basin, useful in order to evacuate the flows that cannot undergo lamination because it has the same dimensions in input and in output.

The skimming area of the pipe laid down on the upper surface of the gravel, pre-configured by assigning a constant project slope, can be protected by cement prefabricated elements and be inspected with a removable covering on the same level with the footstep.

It is advantageous for the basin's durability the construction of a small decantation well at the pluvial basis, not necessarily siphoned, with the purpose of avoiding pluvial water to leave as a sediment the mud collected from the covering inside the gravel, so reducing in time the inflow volume or compromising the draining capacity of the soil.

3. HYDROLOGIC ANALYSIS OF THE SYSTEM

The analysis has the purpose of identifying the hydraulic parameters necessary to the project engineers in order to perform the dimension configuration of the urban drainage networks.

Fundamental data in the collectors' calculation is the down flow coefficient φ of a surface o of a system.

As far as the described device is concerned, the system down flow coefficient can be calculated (covering, pluvial, small well, dispersing micro-basin) by applying the simple principle of mass conservation.

The calculation algorithm, developed by discretizing the physical phenomenon with a finite elements numerical modelling, is the one known in hydraulic literature with the name “only rain”, which neglects the kinematics generated by the movement of the water from the covering collecting pluvial to the dispersing micro-basin and from this one to the sewer.

In the discretized time interval Δt the following equation must hold:

$$\left[\left(V_p - V_a\right) - V_i\right] - V_c = V_s$$

where the symbols have the following meaning:
V_p = net rained volume on the collecting basin of the pluvial;
V_a = out flowed volume from the micro-basin directly into the sewer;
V_i = infiltrated volume in the subsoil through the dispersing micro-basin;
V_c = detention volume by the micro-basin, in dispersion at event completed;
V_s = discharged volume in the sewer following the overflow micro-basin.

By V_p (net rained volume) we mean the product of the surface S of the basin out flowing in the basin, the height h of rain in the time interval Δt and the down flow coefficient φ of the surface S; therefore, the relation holds $V_p = S \times h \times \varphi$. The rain conditions have important consequences on the down flows formation, therefore the calculation of this volume in the time interval Δt has been modeled both as the rectangular hyetograph and as well as the maybe more realistic Chicago model.

By V_a (out flowed volume) we mean the product of the time interval Δt and the flow capacity q compatible with the continuous discharge system in the sewer (by assuming it identical to the rain intensity multiplied by the surface S of the basin with upper limit value equal to the chosen or imposed lamination).

By V_i (infiltrated volume) we mean that volume that infiltrates in the subsoil through the draining surface (bottom and walls) of the dispersing micro-basin; it is calculated as the product of the draining surface of the basin Sd depending on its morphology and the infiltrated thickness s in the time interval Δt; the initial time of this phenomenon is fixed in the moment in which

$$V_p - V_a > 0$$

That is to say in the moment when in the basin rain water, which cannot be drained in the sewer with the constant discharge, starts percolating.

The infiltrated thickness s, according to Paoletti formula based on Horton theory, equals to

$$s = F_s \times t + \left(F_0 - F_s\right) \times \frac{\left(1 - e^{-kt}\right)}{k}$$

where the symbols have the following meaning:
Fs = infiltration speed in the saturated soil; F_0 = infiltration speed in the soil at the initial time;
k = quickness of the variation in time of the parameters Fs and F_0 ; t = time elapsed since the starting time 0.
By V_c (detention volume) we mean that water volume that it is possible to store in the micro-basin; it is an input data, out of which the project choice of the basin typology (if this is realized with checked gravel limited by the draining material, it is necessary to keep in consideration the % of voids in order to deduct the required gravel's quantity for the basin construction) can be inferred. The detention volume will naturally drain in the subsoil when the event is concluded, in a way to restore the micro-basin functionality in order to face future episodes.

As a simplification of the calculation algorithm, the hypothesis that the detention volume V_c gets created and grows only after the start of the draining in the subsoil is made, provided that the following relation holds:

$$\left(V_p - V_a\right) - V_i > 0$$

Whenever the detention volume V_c reaches the maximum value compatible with the system, the value of the discharged volume V_s , that increases the value of the out flowed volume V_s in the system public drain collector, is determined.

Therefore the theoretical calculation of the average down flow coefficient φ of the system "dispersing micro-basin" is obtained by the ratio of the summations (from the time 0 to the time t of the end of the event) of the volumes calculated in the discretized time that is to say by the ratio of the cumulated volumes during the event given by the following summation

$$\varphi = \sum\nolimits_{\Delta t_0}^{\Delta t_n} \frac{\left(V_a + V_s\right)}{V_p}$$

Clearly the choice of the pluviometric curve of possibility is of a particular influence on the results, because the rain volumes increase on equal time duration.

The subsoil infiltrating capacity (the water dispersion from the basin) is instead almost negligible for intense phenomena, assuming a relevant importance only for events lasting longer than few hours, even if it's necessary to the micro-basin in order to ensure the drainage of the lamination volume.

4. NUMERICAL RESULTS

Two constructive typologies of micro-basin have been examined, here below indicated as type "A" and type "B" , whose only difference is the useful volume for detention.

The data common to the problem are the following.

Dispersing micro-basin (made as in *figure 1*) servicing a fallpipe having a collection surface of 40 m^2 with an down flow coefficient of its own equal to 0.95; realized with the creation of a parallelepiped in checked gravel (with void % equal to 30); the inflow allowed directly in the sewer is not superior to 0.08 l/s (that is to say roughly 20 l/hm^{2}s), obtained through a cut with cylindrical sector (with height of only 0.01 m roughly) of an area of 0.80 m of the pipe in PVC diameter 100 mm and slope 1‰ that is displaced without interruption between the small decantation well at the pluvial basis and the public sewer.

A mass conservation calculation has been performed with the hypothesis of:
- hyetograph Chicago, with partial fragmentation at instant 0.5 of the total duration;
- recurring time of the event: 5 years, 10, 25;
- duration of each event for rains lasting less than 1 hour: 15 minutes, 30', 45', 60';
- duration of each event for rains lasting more than 1 hour: 3 hours, 6, 12, 24.

The curves of pluviometric possibility are those elaborated for the municipality of Poviglio, province of

Reggio Emilia, positioned barycentrically in the central-Emilian Po plain, south of the Po river, whose coefficients "a" and "n" of the monomial curve of pluviometric possibility $h = at^n$ are listed in *table 1.*

$h=at^n$	events > 1 hour		events < 1 hour	
years	**a**	**n**	**a**	**n**
5	39	0.19	42	0.67
10	48	0.16	52	0.65
25	58	0.14	62	0.64

Table 1 : coefficients of the monomial curve of pluviometric possibility.

As far as the choice of values of subsoil infiltration is concerned, in order to be particularly cautionary, we have adopted those of soil SCS type D (F_s = 2,5 mm/h and k = 2 h^{-1}), and also have chosen F_o reduced to merely 10 mm/h (instead of 76 mm/h) considering that the infiltration happens in the subsoil and not in the superficial ground.

4.1 Numerical elaboration for micro-basin type "A"

The micro-basin is the one represented in *figure 1* that results equipped with a detention volume equal to 0.8 m^3 obtained with a parallelepiped of checked gravel with a basis of m 1.80 x1.80 and depth of 0.8 m.

The ratio between the volume useful for the detention (0,8m^3) and the draining surface in the micro-basin (40 m^2) is equal to 2/100.

In *table 2* the different results are shown for ease of use:

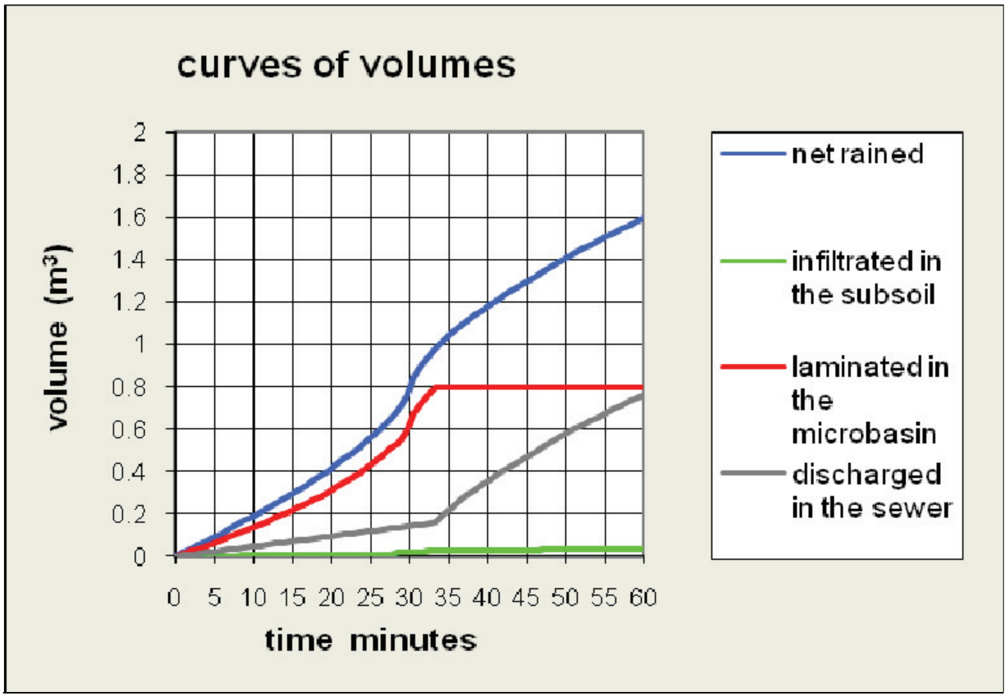
events < 1 hour				
coefficient (φ)		return period (Y)		
		5	10	25
duration event (minutes)	15	0.11	0.09	0.17
	30	0.18	0.34	0.44
	45	0.33	0.47	0.55
	60	0.45	0.55	0.61

events > 1 hour				
coefficient (φ)		return period (Y)		
		5	10	25
duration event (hours)	3	0.51	0.60	0.64
	6	0.55	0.61	0.66
	12	0.58	0.63	0.67
	24	0.59	0.63	0.67

Table 2 : report autput coefficient down flow for micro-basin type A.

Some reductions of the down flow coefficient "φ" can be observed with the growth of the recurring time of the event (Y): they are the consequence of the increase of the denominator (rained volume) with the numerator remaining constant (volume discharged in the sewer) that occurs when the lamination volume of the micro-basin is not saturated by the rained volume during the event. On the contrary, when the detention volume by the micro-basin is full, then the volume discharged in the sewer increases, causing the downflow coefficient again to grow with the growth of the recurring time of the event, as logically expected. The above described logical justification finds confirmation in the sequential examination of the graphic outputs.

We also relate in *figure 2,3*, some interesting diagrams with partial trends of the volumes involved and of the capacities in input and in output of the system for the only event with duration 60'.



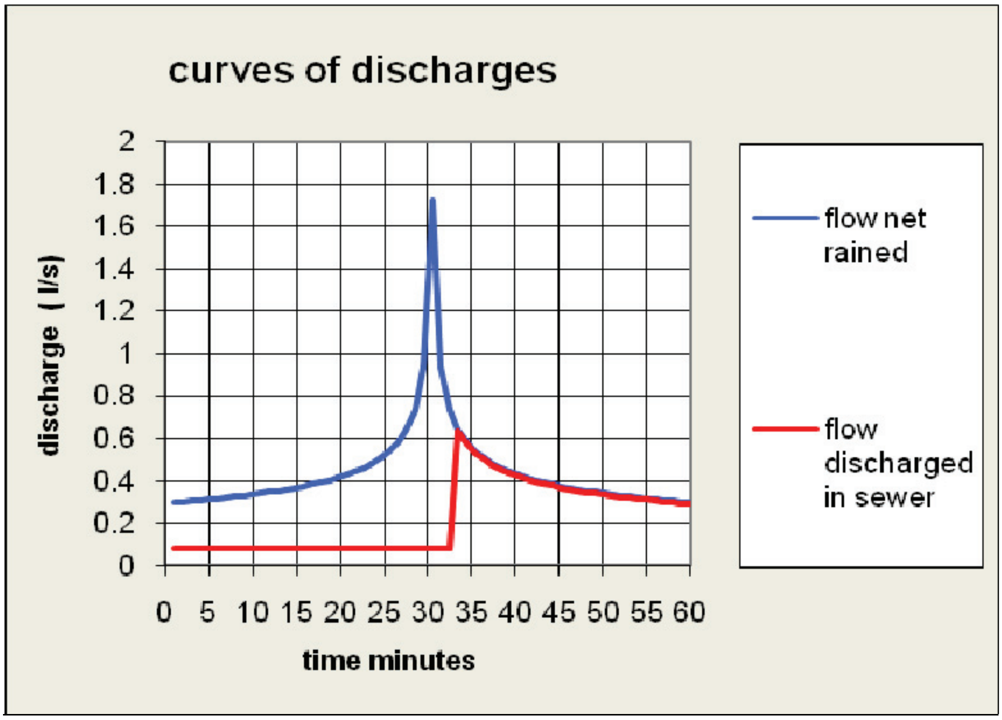


Figure 2 and 3: micro-basin type “A” with recurring event time equal to 5 years (rains <1hour):- accrued volumes' curves;- curves of instantaneous capacities in input and in output.

4.2 Numerical elaboration for micro-basin type “B”

The micro-basin is like the one in *figure 1* but with lamination volume equal to 1.50 m^3 obtained with a parallelepiped of checked gravel with a basis of m 2.05x2.05 and depth of 1.20 m.

The ratio between the volume useful for the detention and the draining surface in the micro-basin (40 m^2) is 3.75/100.

events < 1 hour				
coefficient (φ)		return period (Y)		
		5	10	25
duration event (minutes)	15	0.11	0.09	0.07
	30	0.14	0.11	0.09
	45	0.16	0.13	0.20
	60	0.17	0.20	0.32

events > 1 hour				
coefficient (φ)		return period (Y)		
		5	10	25
duration event (hours)	3	0.31	0.27	0.37
	6	0.37	0.32	0.41
	12	0.42	0.36	0.44
	24	0.46	0.41	0.44

Table 3: report autput coefficient down flow for micro-basins type B.

In *table 3* for ease of comparison the different results obtained are shown, for their fluctuations the same observations presented for table 2 hold, even if with a more evident behaviour.

5. CONCLUSIONS

The comparison among the downflow coefficients φ of a covering directly connected to the sewer and those obtained by means of interposition of the dispersing micro-basin show a remarkable detention effectiveness of the system, which is enhanced in the event of rains lasting less than 1 hour.

The reduction of the coefficient φ for the rains lasting few hours is less significant, but still appreciable. For these rains we also highlight the occurrence, during the event, of its maximum value being reached, thanks to the contemporary infiltration in the soil.

The dropping of the instantaneous meteoric capacities is particularly significant mainly if we consider the maximum values both in input as well as in output of the system, as evidently shown in the graphic results.

The infiltrated volumes are in percentage scarcely meaningful in the system’s balance, but the subsoil dispersion of the rain water finds anyway its need to be for the restoration at the end of the event of the maximum detention volumes of the micro-basin, as well as for having environmental validity for the renourishment of the ground waters.

The studied system finds an economic validity in the field of urban drainage infrastructures allowing to reduce the collectors’ dimensions as well as to avoid the construction of the final basin at the output of the lots division.

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